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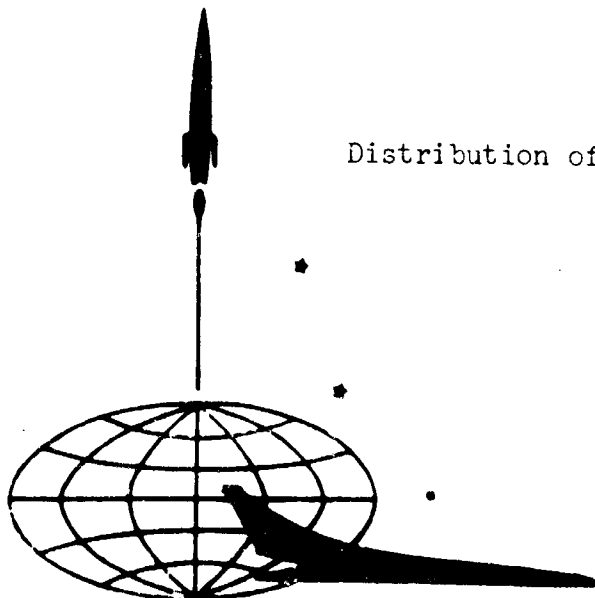
SOVIET LONG-RANGE SPACE - EXPLORATION PROGRAM

Analytical Survey

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ABSTRACT

This analytical survey is based on Soviet open sources published 1956-1965. It is one of a series of reports dealing with the Soviet long-range space-exploration program and is concerned, in particular, with lunar surface research. Information not directly related to this subject has been included because of its broad implications for study in this field. This report may prove useful to lunar mission planners, both those concerned with the purely scientific aspects of the moon's surface and immediate subsurface and those involved in the development of lunar exploration vehicles and in the establishment of permanent lunar bases. Information is divided into the following sections: Section I. Photometric observations; Section II. Spectral observations; Section III. Measurement of lunar temperatures; Section IV. The meteor slag theory; Section V. Interpretation of lunar craters; Section VI. Lunar seismicity; Section VII. Radio echo studies; Section VIII. Lunar atmosphere. The main purpose of this report is to present an up-to-date summary of the current state of Soviet knowledge concerning the surface of the moon. The question of lunar topography is of obvious importance to the landing of instrument packages and manned vehicles on the moon. Every major aspect of the current lunar research program has been considered and all pertinent evidence available from Soviet sources has been reviewed. Much Soviet effort in lunar studies has been directed toward the problems which will have to be solved in order to ensure a tolerable margin of safety for the astronauts who will be going there. In the Conclusion the author summarizes the Soviet views on the lunar surface layer--views which he deems often contradictory and sometimes hardly acceptable. There are 17 references listed at the end of the report.

Surveys of Communist World Scientific and Technical Literature

SOVIET LONG-RANGE SPACE-EXPLORATION PROGRAM

Analytical Survey

ATD Work Assignment No. 57
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FOREWORD

This report is one in a series of reports dealing with the Soviet long-range space-exploration program. It is based on Soviet open-source materials available at the Aerospace Technology Division of the Library of Congress and is concerned with lunar surface research. Information not directly related to this subject has been included because of its broad implications for study in this field. This report may prove useful to lunar mission planners, both those concerned with the purely scientific aspects of the moon's surface and immediate subsurface and those involved in the development of lunar exploration vehicles and in the establishment of permanent lunar bases.

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INTRODUCTION

The main purpose of this report is to present an up-to-date summary of the current state of Soviet knowledge concerning the surface of the moon. The question of lunar topography is of obvious importance to the landing of instrument packages and manned vehicles on the moon. Every major aspect of the current lunar research program has been considered, and all pertinent evidence available from Soviet sources has been reviewed.

The results of many of the studies of lunar surface characteristics have been reviewed and evaluated in chapters by Fesenkov and Kozyrev, appearing in *Physics and Astronomy of the Moon*, and by Sharonov, Markov, Sytinskaya, Barabashev, Zel'tser, Kaydanovskiy, and Khabakov, published in a monograph entitled *The Moon*. The present report draws heavily on these sources.

In planning manned lunar expeditions, writes V. V. Sharonov [1], it will be necessary to have relatively complete information on the physical and chemical properties of the lunar surface. In particular, it will be necessary to know whether it consists of smooth, dense, hard soil, or whether it is made up of a soft, friable material like dust, or of heaps of large fragments of rock, which would make motion over the surface difficult. The presence of compounds possessing high chemical activity may also turn out to have practical importance.

In summing up the information on the physical properties of the lunar surface which we now possess, Sharonov arrives at the conclusion that any hypothesis concerning the nature of the substances spread over any portion of the moon must take into consideration the following, well-established facts.

1) The surface of the moon is everywhere covered with dark matter; this follows from the visual value of the spherical albedo for individual features on the disk of the full moon from 0.05 to 0.15.

2) The differences in color on the moon are extremely small. They can barely be distinguished by the eye, while colorimetric observations give differences in the normal light characteristics of the order of $\pm 0^m.2 - \pm 0^m.3$. The grayish-brown color which is practically identical for all parts of the moon is characterized by the absolute value of the average color excess of yellow light, i.e., the difference between the color indices for the moon and for the sunlight illuminating it, which amounts to +0.3 mag.

3) The distribution of the light flux reflected by direction is such that at all angles of incidence of the solar rays the maximum brightness is in the direction toward the sun.

4) The light reflected by the lunar surface is partially polarized. The degree of polarization is determined basically by the scattering angle (the angle between the incident and the reflected rays) and depends only to a small extent on the angle of incidence of the rays.

5) The atmosphere on the moon, if one exists in some form, is so rarified that it has practically no physical manifestation. In solving various problems, it can be assumed that the lunar surface is subject to the conditions of an airless space identical with that of the interplanetary medium.

6) Thermoelectric measurements of the behavior of temperature during lunar eclipses and during lunation lead to the conclusion that the thermal conductivity of the actual outer layer of the lunar surface is extremely low, being smaller than the values which experiments yield for solid rocks of the granite type by a factor of approximately 1000. This low thermal conductivity corresponds, on the one hand, to pulverized substances and, on the other, to extremely porous substances such as tuffs, pumice, and volcanic slag.

7) The lunar surface is continuously exposed to a number of space factors, including all types of solar radiation (extreme ultraviolet, gamma, and particle radiation), cosmic rays, and collisions of meteors, from the smallest bit of cosmic dust to micrometeors and large meteorites.

SOVIET LONG-RANGE SPACE-EXPLORATION PROGRAM

SECTION I. PHOTOMETRIC OBSERVATIONS

The remarkable manner in which the moon scatters light provides an important clue to the nature of the lunar surface materials. For instance, at full moon the distribution of brightness over the disk is approximately the same at the center as it is near the edges, although every diffusing sphere illuminated by a distant source of light and observed near zero-phase angle must necessarily be brighter in its center [2].

A member of the Committee for Meteorites, Academy of Sciences, USSR, V. G. Fesenkov, considers the photometric properties of the moon to be of the greatest importance for any conclusions about the nature and structure of its surface. According to Fesenkov, the lunar surface has nothing in common with ordinary diffusing surfaces, obeying, in some degree, Lambert's law; on the basis of thermal-radiation studies, consequently, the moon cannot be covered by some uniform layer of dust as some authors have supposed.

Earlier conclusions concerning the structure of the moon's surface were based on purely theoretical considerations; now, however, they are based on direct comparison with different terrestrial models. A most extensive project of this kind was carried out by N. S. Orlova [3] in the laboratory of Leningrad University with a specially constructed indicator. This instrument permits the comparison of every sample with a standard plate normally illuminated, at different angles of incidence and reflection. As can be seen from the survey of indices for numerous samples investigated in this way, the following are the principal types of reflection for terrestrial minerals: 1) orthotropic minerals, which satisfy Lambert's law - at least for angles of incidence between 0° and 40° ; 2) reflecting minerals, with maximum intensity in the direction of the regularly reflected ray; 3) completely rough minerals with maximum reflection in the direction of the incident ray; and 4) mixed minerals, with two maxima in the directions of regularly reflected and incident rays.

Volcanic slugs and slugged lava as well as different kinds of tuffs are related to the third type, with some analogy with the moon. According to Orlova, the surface of the moon must be classified into the third type; however, it is characterized by a very much greater elongation of the corresponding index in the direction of the incident beam, greatly surpassing every terrestrial sample. Consequently, according to these results, the lunar surface exhibits the greatest similarity with models covered by deep holes with vertical walls and sharp edges.

The photometric behavior of every detail on the moon, as well as its integral brightness at each phase-angle, can be represented by a single function referring to the positive limb of the lunar crescent. This indicates that all lunar details apparently have the same structural properties. This micro-structure is such as to give a very strong maximum reflection in the backward direction; therefore, the effective indices of scattering cannot be that of small inhomogeneities, but of grains considerably greater than the wavelength of visible light [2].

The latest photometric data, writes Ye. L. Ruskol [4], strongly suggest that the density of the uppermost layer of the moon is extremely low (about 0.3 g/cm^3). The photometric properties of the moon, however, can furnish information concerning only the top millimeter of the lunar surface. In summary, it is concluded that the lunar surface is everywhere covered by a layer of rock dust whose particles have an average size of the order of 10μ . The grains of rock have been darkened by exposure to solar radiation or some other agent and arranged by micrometeorite bombardment into a porous material with a bulk density only one-tenth that of solid rock. The depth of the dust layer is unknown, but must be at least a few millimeters.

SECTION II. SPECTRAL OBSERVATIONS

At the Pulkovo Observatory in Leningrad, USSR, N. A. Kozyrev conducted in November 1958, and in October 1959, systematic spectral investigations of details of the lunar surface near the terminator [5]. These investigations were carried out with the 50-inch reflector of the Crimean Astrophysical Observatory, by use of a prism spectrograph, with a camera giving a linear dispersion of about 23 Å mm at H γ . The scale of the spectrogram was 10 seconds per mm, and the scale of the image on the slit was 0.05 mm on Kodak 103 aF plates. All photographs were photometrically standardized by use of a wedge photometer. Stimulated by Alter's observations, Kozyrev made a special point of obtaining the spectra of details inside the crater Alphonsus.

The spectrum of the ashen light was found to be strong in comparison with the sky spectrum adjacent to the moon and it was concluded that, for practical purposes, the moon could have no ionosphere and no magnetic field*, and that solar radiation would fall unimpeded and undeviated upon the moon's surface to cause luminescence of the minerals which were present.

While taking spectrograms, Kozyrev noted that on 3 November 1958 at 0100 U. T., the central peak became "strongly washed out and of an unusual reddish hue." At 0300 U. T. a second lunar spectrogram was commenced. This exposure lasted for half an hour, to 0330 U. T. and Kozyrev observed that the central peak of Alphonsus looked unusually bright and white. A third spectrogram was then taken, from 0330 until 0340 U. T. When examined, the first two spectra were noted to deviate from the normal appearance characterized by all previous spectra and by the third one. The first spectrogram showed that in violet light the central peak was much less bright than usual (compared with adjacent parts of the crater), and the second spectrogram showed broad emission bands. Examining Alphonsus on the next night, Kozyrev found that Alphonsus had returned to normal.

Kozyrev has proposed the following interpretations of these observations. First, there was an ejection of a reddish-colored volcanic ash, or dust, in the vicinity of the central peak of Alphonsus. This was followed by an efflux of gas, lasting for not more than 2 1/2 hours and not less than 30 minutes, which gave rise to the observed emission spectrum. The gas, he said, could have come from magma rising to the moon's surface.

*Both Russian probes, including Lunik I (which passed within 6000 km of the moon's surface) and Lunik II (which crashed on the moon), later failed to detect a lunar magnetic field in excess of 10^{-3} oersted.

The actual emission is said to have been centered about 1.5 km to the east side of the central peak, nearer than the peak to the setting sun. Kozyrev said that the sun's ultraviolet light could probably penetrate only a short distance into the cloud. He estimated the thickness of the gas cloud to be of the order of 1.3 km, and the density of the carbon molecules making up the cloud to have a maximum of 10^{11} particles per cubic centimeter. In order to further substantiate his theory, Kozyrev conducted another series of spectral observations, this time of the Aristarchus crater, in the latter part of 1961 [6]. The same 50-inch reflector of the Crimean Astrophysical Observatory, and a low-dispersion spectrograph (about 150 Å mm near the H_γ line) were used in these observations. Reporting on his findings he says, "On 30 November 1961 the Moon was in its last quarter. The spectrograms of the Aristarchus crater and its surroundings were obtained on the nights of 26, 28, and 30 November and 2 and 3 December 1961. During these nights, quite a large number of spectrograms of the details of the Aristarchus and Herodotus craters were obtained together with the spectrograms of the crevices, neighboring small craters, and other details of the relief.

"A series of emission lines could be seen only on the spectrograms taken on the nights of 26 and 28 November and on the two spectrograms of 3 December. These could be discerned right in the center of the Aristarchus crater even without any photometric measurements. The spectrum lines were obtained under exceptionally favorable atmospheric conditions. Apparently the area on which the emission lines appeared did not exceed several square kilometers.

"The group of emission lines observed in the center of Aristarchus crater stood out sharply at the red end of the spectrum. The length of waves of the border-line amounted to 4634 Å with an error of 1 Å. The whole group of lines stretches up to 4390 Å, and has a series of maxima. These data definitely establish that the emissions observed are of a gaseous nature. An important confirmation of such a conclusion is provided by the fact that on the photographs taken on 3 December emission lines project somewhat into the spectrum of the shadow cast by the eastern side of Aristarchus' wall. Hence, one can conclude that the source of emission rises to a certain height above the crater's surface. It is quite possible that the emissions observed close to the last quarter of the moon are not accidental, and that the ejection of gases is made easier by the fact that the sun's rays heat the crater surface.

"The emission of molecular hydrogen observed in the fumarole ejections of Aristarchus' crater cannot be the result of the photodissociation of water vapor, since this process brings about the formation of H and OH. It is scarcely possible to have molecular hydrogen appearing as a result of the photodisso-

ciation of other molecules. Therefore, it can be assumed that molecular hydrogen is formed and accumulated in the depths of the moon.

"Such a condition is in keeping with the presence of local accumulation of hydrogen in the earth's crust. Moreover, chemical reactions in which molecular hydrogen is formed usually occur at high temperatures. That is why the ejection of molecular hydrogen from inside the moon indicates the existence of a high temperature inside our natural satellite, just as inside the earth.

It should be stressed that to date Kozyrev is the only Soviet authority who claims to have positive proof that the moon is no longer to be considered completely inactive, and that his evidence does not satisfy all astronomers.

SECTION III. MEASUREMENTS OF LUNAR TEMPERATURES

The determination of temperatures both on the surface and in the interior of the moon are necessary for computing its thermal balance. This may be of assistance later in answering the question of whether or not the moon has a heated core.

The study of the moon's infrared radiation provides information on the thermal properties of the upper layer to a depth of about 20 cm [4]. The surface of the moon is imagined to be of a homogeneous, semiinfinite solid material characterized by a thermal conductivity k , a density ρ , and a specific heat c . This combination of parameters can be determined from previous observations using $\gamma = (k\rho c)^{-1/2}$. Observations of the moon during eclipse have yielded γ values approaching 1000. The recent observations of the moon's thermal radiation during the lunation period, made by V. D. Krotikov and V. S. Troitskiy, resulted in a value of $\gamma = 350 \pm 75$. These data apply to the thicker upper layer, since the observed radiation originates at a depth 40 to 50 times greater than the wavelength.

A method has been devised by V. S. Troitskiy and associates for determining the average density at depths which give rise to radiation; in this method Troitskiy used the dielectric constant ϵ , assuming that the density and electrical parameters of the medium do not change with depth and are the same for the entire lunar disk. The latter assumption was necessary due to the fact that the receiving instruments used by Troitskiy did not yield resolution of surface details. The formula, derived empirically for various dry rocks, used for determining the density is $\sqrt{\epsilon} - 1 = c\rho$, where $c \approx 0.5 \text{ cm}^3 \cdot \text{g}^{-1}$.

High-resolution measurements at millimeter wavelengths on large radiotelescopes made discrete temperature determination possible. They showed that nighttime temperatures of maria average 6°C higher than those of the continents. The same conclusion follows from the thermal-flow measurements in the infrared region of the 8—13-micron wavebands and the 3.6-micron waveband.

The distribution of energy in the radiation spectrum of celestial bodies approaches that computed for an absolutely black body [7]. Therefore, astrophysical computations, which are generally made assuming that the planet behaves as an absolutely black body, are also more or less approximate. In this case, the temperature of a planet can be determined in the following fashion: the amount of energy obtained by it from the sun for each square centimeter of the surface perpendicular to the solar rays is equal to ϵ/r^2 , where ϵ is the solar constant, and r is the distance of the planet from the sun expressed in astro-

nomical units. If we consider the moon as an absolutely black body, we shall have to regard all the energy falling on a unit surface as totally absorbed, raising its temperature. At the same time, the moon will have to radiate the energy E from one square centimeter of its surface into space according to the Stefan-Boltzmann law $E = \sigma T^4$. Consequently, the temperature of the moon in a stationary state can be computed in this case from the equation $\epsilon/r^2 = \sigma T^4$. As indicated before, this is only an approximated computation, and the temperature of the lunar surface is usually computed from radiometric measurements.

Using the 125-cm telescope of the Crimean Station of the Astronomical Institute im P. K. Shternberg, M. N. Markov, and V. L. Khokhlova [8] measured radiation from the lunar surface in two spectral regions during the lunar eclipse of 7 August 1963. In July of the same year, they also measured radiation from the hidden part of the moon using the 125-cm telescope of the Crimean Astrophysical Observatory. A bolometer served as a radiation detector for the 8—13- μ spectral region, while a PbS photoresistor cooled by liquid nitrogen was used for the $\lambda = 3.6 \mu$ spectral region. The radiation beam was split by means of an oscillating mirror modulator and sent to two channels, the signals of which were recorded simultaneously on two automatic potentiometers.

The measured flux is represented by the integrals

$$I_{3.6\mu} = \omega_1 \int_{3.6\mu} \epsilon_\lambda B_\lambda(T) k_\lambda^n k_\lambda^a d\lambda + \omega_1 \int_{3.6\mu} I_\lambda^\odot r_\lambda k_\lambda^n k_\lambda^a d\lambda, \quad (1)$$

and

$$I_{8-13\mu} = \omega_2 \int_{8\mu}^{13\mu} \epsilon_\lambda B_\lambda(T) k_\lambda^n k_\lambda^a d\lambda, \quad (2)$$

where ϵ_λ is the radiation coefficient of the lunar surface, $B_\lambda(T)$ is the Planck function, k_λ^n and k_λ^a are the transmission functions for instrument and atmosphere, ω is a factor which considers the speed of the lens and the size of the area measured on the moon, $I_\lambda^\odot r_\lambda$ is the intensity of solar radiation reflected by the lunar surface (essential for the 3.6- μ area only).

The determination of k_λ^n is simple; that of k_λ^a appears uncertain when observations are made when there is a relatively high water content in the earth's atmosphere and the moon is in a low position. From the relationship between the measured flux and the illumination of a given region of the lunar surface during the penumbral phase, the authors determined the reflection coefficient for the lunar surface for the $\lambda = 3.6\text{-}\mu$ spectral region from the slope of the linear portion (low illumination, reflected radiation) (see Fig. 1). Inasmuch as observations in this case were made at full moon, the reflecting property can be characterized by the normal albedo, or $\rho_{0,3.6 \mu}$. Of the four points of the moon's surface considered in Fig. 1, points 1 and

2 refer to the bright continental regions, curves 3 and 4 refer to the dark sea regions. Point 2 is found near the edge of the disk, points 1, 3, and 4 are located near the center of the disk. The dashed line represents the extrapolation of the linear dependence (reflected radiation). In the measured I_{λ} flux, plotted along the axis of the ordinates, the atmospheric absorption has not been considered.

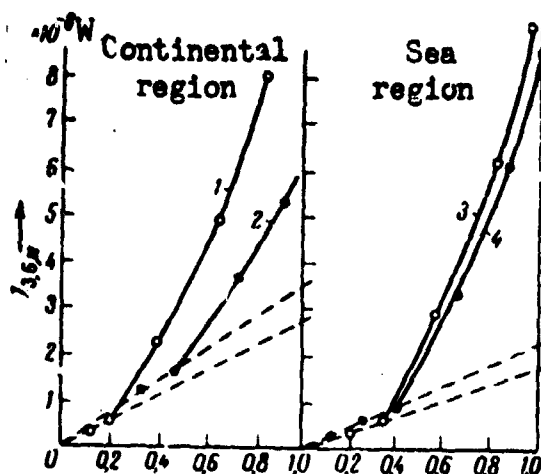


Fig. 1. Dependence of $I_{3.6 \mu}$ on the eclipse phase for four points on the lunar surface

The magnitude of $\rho_{0.3.6 \mu}$ varied from 0.25 for seas to 0.55 for continents, which considerably exceeded the value of ρ_0 for the visible region of the spectrum (see Fig. 2).

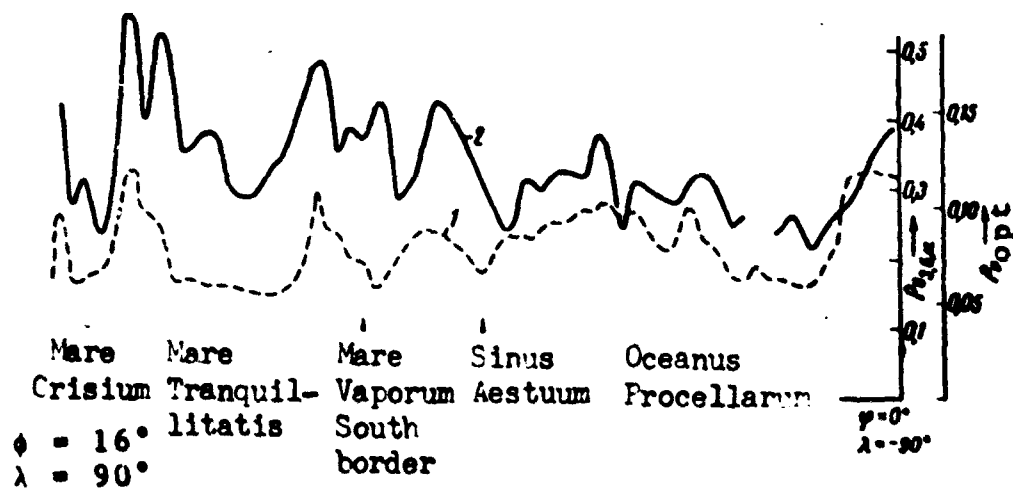


Fig. 2. 1 - Photometric section (in the optical region of the spectrum) through the equatorial region of the moon; 2 - the normal albedo for the same section

As in the visible region, no darkening toward the edge of the lunar disk was observed. On the whole, good agreement was found between the variations of ρ_0 in the optical region of the spectrum and those in the $\lambda = 3.6 \mu$ region. Assuming that the phase integral for 3.6μ is the same as that for the optical

part of the spectrum and equals 0.694, the radiation coefficient $\epsilon_{3.6 \mu}$ was found to vary between 0.83 (seas) and 0.62 (continents). The color temperature has been obtained from expressions (1) and (2) above on the assumption that $\epsilon_{3.6 \mu} = \epsilon_{8-13 \mu}$. For a subsolar point, this temperature varies between 405 and 440° K (depending on the allowance made for atmospheric transparency). The brightness temperature in the $\lambda = 3.6 \mu$ region amounts to 407 and 433°K, respectively. The near agreement of these temperatures suggests that $\epsilon_{3.6 \mu} \approx \epsilon_{8-13 \mu}$. The moon can thus be considered as an approximately gray emitter.

The authors measured the thermal flux from the dark side of the moon over a period of three nights. During each of these nights they scanned the same section of the moon traversing Mare Crisium, Mare Serenitatis, and the Hassendi crater. The flux from the continental section of the surface was found to be about one half that from the sea region, although the former was in all cases closer to the receding terminator. The difference between $\epsilon_{3.6 \mu}$ for seas and continents amounted to only 25%, while that for $\epsilon_{8-13 \mu}$ was even lower. It appears that the differences between the fluxes should be ascribed to variations of the $\gamma = (k/c)^{-1/2}$ value between seas and continents, rather than to variations in $\epsilon_{3.6 \mu}$ and $\epsilon_{8-13 \mu}$ values. According to calculations, for an average $\gamma = 600$ value, the observed difference between the fluxes corresponds to a variation in γ of 20%.

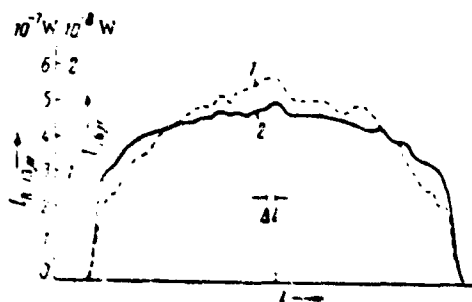


Fig. 3. Recordings of fluxes $I_{3.6 \mu}$ (1) and $I_{8-13 \mu}$ (2) at full moon (40 min after the termination of the eclipse) for the equatorial section

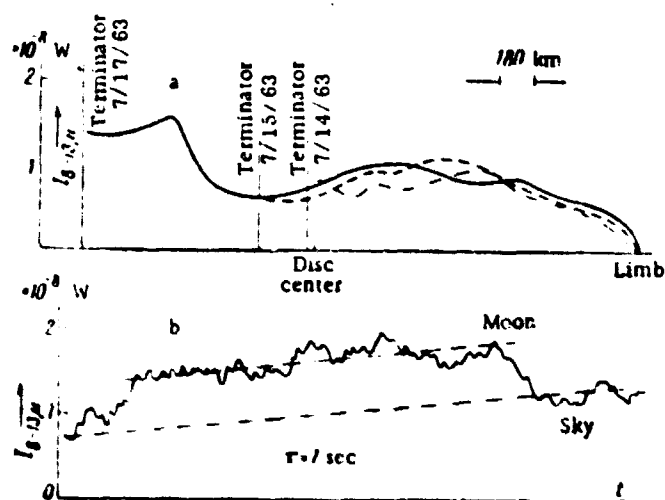


Fig. 4. a) Average recordings of the thermal fluxes from the unilluminated areas of the moon; b) recording of the fluctuations in the flux $I_{8-13 \mu}$ from the sky background and from an unilluminated section of the moon

An equatorial section at full moon, immediately after the eclipse, for the two spectral regions $\lambda = 3.6 \mu$ and $\lambda = 8-13 \mu$ is shown in Fig. 3. Average recordings of thermal fluxes from the dark side of the moon are represented in Fig. 4.

The "artificial moon" temperature-measurement method developed recently by V. S. Troitskiy at the Gor'kiy Scientific Research Institute of Radiophysics, and thermal-radiation measurements of the moon at different wavelengths, make a more accurate determination of the constant temperature component of the moon at various depths possible [4]. In the centimeter region (0.4, 1.6, 3.2, and 9.6 cm), the constant temperature component increases from 210 to 220° K with increasing wavelength, reaching 230° K at the 35-cm wavelength. Troitskiy does not believe that this rise in temperature is due to heat coming from the sun since no phase dependence of temperature could be detected in the decimeter region. He also scrutinized potential external interferences and instrument errors which might result in an increase of temperature with wavelength. There are obvious indications that temperature increases with depth within the approximately 20-m thick surface layer. The much smaller temperature gradient below this level is ascribed to the presence there of more compact rocks having a considerably higher thermal conductivity compared with the surface layer. Assuming the temperature gradient to be the same for the entire layer under observation (0°/8 at the centimeter wavelength), Troitskiy estimated its magnitude at 1°/5 per meter which, for $\gamma = 350$, yields a thermal flow from the moon's interior of about $1 \cdot 10^{-6}$ cal/cm².sec. Considering that the thermal flow given off equals the flow generated, this flow would correspond to a heat generation of some $2 \cdot 10^{-7}$ cal/g per year, i.e., 4 to 5 times larger than the heat obtained for an abundance of radioactive elements of $n = 1$. Since the temperature gradient could be observed only within the uppermost layers of the lunar crust, γ -values close to 1000 ought to be used. For $\gamma = 1000$, the heat flow at the surface would, according to Troitskiy, amount to $0.35 \cdot 10^{-6}$ cal/cm² per sec, and the average heat generated per 1 g of the lunar matter would exceed 2 to 3 times that for $n = 1$. Considering that $n = 1$ abundance is characteristic of both chondrites and terrestrial matter, and that the surface heat flow on the moon equals its generation due to the decay of radioactive elements in its interior, Troitskiy concluded that the radioactive-element content of the moon is several times that of chondrites and terrestrial matter, and that, as a consequence, the interior of the moon must be hot at a relatively small depth.

SECTION IV. THE METEOR SLAG THEORY

The meteor slag theory of the origin of the lunar surface is based on a set of views and assumptions which are the result of thirty years of studies carried out at the Laboratory of Planetary Astronomy of the Leningrad University Astronomical Observatory [9]. The chief proponent of this theory, N. N. Sytinskaya, has investigated the brightness-color diagrams of the moon and many terrestrial materials and found no agreement between those of the moon and any terrestrial material. Sytinskaya suggested that the entire lunar surface is covered by a thin crust consisting of a light-weight, extremely porous, dark-colored slaggy material of meteoric origin. Since the moon is not protected by an atmosphere, micrometeorites hit the moon at a speed of tens of kilometers per second. At the time of the impact, immense kinetic energy is converted instantly into heat. An explosion takes place. Both the meteorite and the ground around the point of impact are vaporized. The boiling rocks develop into a bubbly, slag-like mass. The dark color of this mass is due to the decomposition of iron-containing minerals, such as olivine, and the formation of black ferric oxides. Since micrometeorites are scattered evenly over the entire lunar surface, the spongy layer can be found all over the moon.

Another advocator of the meteor-slag theory, V. V. Sharonov, maintains that the surface of the moon is uniform throughout and that the highly porous, slag-like sections of the lunar soil do not alternate with areas consisting, for instance, of exposed granitic or basaltic rock faces [9]. By a study of both the light and the heat coming from the moon, Sharonov was led to propose that the surface was covered with a spongy, vesicular clinker formed by the action of meteorites. The fact is, he says, that if there were areas on the moon, different as to their structure, large enough (at least 100 km) to be observed through a telescope, such areas would have been easily detected. The manner in which the intensity of the light from the moon varies with phase angle would differ from one area to the other. Each spot of a smooth rocky ground lying in the midst of a porous slag would at full moon become darker relative to its surroundings since it would not reflect light toward the sun as strongly as would the areas with a porous, spongy-slag structure.

Sharonov also noted that photographs of the averted hemisphere of the moon taken from aboard the automatic interplanetary station, launched by the Soviet Union on 4 October 1959, did not reveal any dark spots near the edge of the lunar disk. This proves that the other side of the moon has the same porous structure as does the surface of the hemisphere facing the earth. All these lunar features, writes Sharonov, strongly suggest that lunar slag is of meteoric rather than volcanic origin. Volcanoes

and their eruption products differ from each other. It is very unlikely, therefore, that these eruption products would give rise to a uniformly structured surface layer. On the contrary, meteorites are not related to the nature and the structure of lunar formations, and the result of their activity should be the same over the entire lunar surface.

SECTION V. INTERPRETATION OF LUNAR CRATERS

The dominant surface features of the moon are approximately circular depressions, which may be designated by the general term crater. Solution of the origin of the lunar craters is fundamental to the unravelling of the history of the moon and may shed much light on the history of other planets as well. Up until recently, writes V. Bazykin [10], these craters were considered proof of intense volcanic activity some billions of years ago. Today, this view is vigorously disputed. It is now believed that most of the lunar craters were formed by the impact of a large number of meteorites falling upon the moon. Theoretical as well as experimental studies have shown that the meteorite-impact hypothesis for the origin of the lunar craters and maria agrees well with the many observed facts. It conforms to the theory of the formation of the earth and other planets from a gas-dust cloud which, in the course of its evolution, had changed to a cluster of solid particles which, in turn, had later given rise to planets. This theory was founded by Academician O. Yu. Shmidt and is now being further developed by a group of Soviet scientists headed by B. Yu. Levin. One of the convincing arguments favoring the meteorite crater-forming hypothesis has been the recent discovery of a number of large terrestrial craters. Nevertheless, Bazykin concludes, the fall of meteorites which might have produced most of the lunar craters can not explain the origin of such features of the lunar relief as the long mountain chains and the craters on the top of the central peak of some large cirques.

According to K. P. Stanyukovich and V. A. Bronshten [11], the distribution of craters on the surface of the moon is one of the most important indications of their method of formation. If the craters, they say, were formed as a result of separate, random impacts of large meteorites, they should be distributed over the surface of the moon more or less evenly. However, the evidence does not at all agree with this assumption. Craters are distributed over the lunar surface extremely unevenly and, together with regions which are rich in craters, equally vast territories (chiefly the maria) are encountered where there are almost no craters.

Another indication is the number of overlapping craters. If the meteorite hypothesis in its original form is adopted, the number of such pairs of craters (of the type of Theophilus and Cyrillus, Alphonsus and Ptolomaeus) should be much greater than that actually observed. To explain this peculiarity, Sadil advanced the hypothesis that the uneven distribution of the craters is the result of the effect of tectonic or other changes in the lunar crust, which took place after the formation of the craters. In exactly the same way, Sadil uses subsequent changes

to explain the small number of overlapping craters, i.e., the more ancient craters had an opportunity to disintegrate before new ones were formed in their place.

It must be remembered, the authors continue, that the maria are regarded by the proponents of the meteorite hypothesis as regions where gigantic lava outpourings took place, drowning ancient craters. However, a study of the submerged ghost craters found on the surface of lunar maria showed that more than 45% of all craterlets located in the maria appear on the walls of these craters. At the same time, the area occupied by ghost craters amounts to less than 20% of the total area of the seas. This clearly points to the nonrandom nature of the location of the craterlets and to their genetic relationship with the ghost craters. Stanyukovich and Bronshten close the argument by inferring that the results of statistical studies do not lend support to the proponents of the meteorite hypothesis, and make it necessary for them to introduce additional, at times very reasonable, assumptions to explain the observed facts.

The hypothesis of the nonrandom distribution of craters on the surface of the moon is also shared by B. Yu. Levin and Ye. L. Ruskol [12]. The lunar craters, they say, are shallow formations and bear virtually none of the features characteristic of terrestrial volcanoes. The apparent depth of the lunar craters is illusory due to the fact that we are used to the shadows that are cast by objects when the sun is high. A shallow crater illuminated obliquely does not at first sight appear any different from a deep crater illuminated at a wide angle. The depth-to-diameter ratio of craters varies with the size of the crater, the depth becoming smaller relative to the diameter with increasing crater size. The depth of a crater (measured from the top of the ringwall) 20 to 30 km in diameter averages 10% of its diameter, that of a crater 100 km in diameter is about 5%, and that of still larger craters is 2.5 to 3%.

A number of craters have a slanting central peak consisting sometimes of several elevations. Among the "youngest" craters (i.e., craters exhibiting a rough relief), measuring more than 10 km in diameter, some 80% have such a central peak. For small craters, the presence of a central peak cannot, as a rule, be determined with certainty. This might be due to the steepness of their inner slopes; the fact is that when the sun is low the floor of the crater is in the shadow cast by the surrounding ringwall.

Numerous cracks are found on the surface of the moon, some as long as 100 km. These cracks, called rills, are shallow depressions no more than a few hundred meters deep and a few kilometers wide, generally disposed in sweeping arcs having radii of curvature in the thousands of kilometers inside the edge of the maria. Levin and Ruskol believe that these rills

are the result of thermal fracturing occasioned by the shrinkage of the once-hot maria upon cooling.

A renowned Soviet selenologist, A. V. Khabakov [13], subdivides lunar ring-mountains into cirques when their bottom is flat like that of a circus arena, and into craters when the bottom of the internal depression is cup-shaped. Craters and cirques differ further by the presence or absence of a central peak. Detailed observations and careful statistical computations have shown that a very considerable difference in appearance and probable origin is noticed in different types of cirques and craters of different order of magnitude. It turns out, according to Khabakov, that very large craters and cirques differ greatly in terms of their size, appearance, and frequency of occurrence, from the smaller ring-mountains which, in turn, differ from the smallest circular elevations.

A great many craterlets are found on the moon. Considering that there are some 20,000 to 30,000 ring-shaped land forms of the lunar macrorelief, there must be, according to selective comparisons, 1000 as many craterlets. There are more than 500 craterlets per 100,000 km² of the lunar surface. The tiniest lunar crater, the so-called "blowhole" crater, has the shape of a deep bowl with a slightly slanting wall. Larger, but still small craters, having a diameter from a few kilometers to a few tens of kilometers, are frequently called parasitic (secondary) craters (when they are concentrated on the outer slopes of the walls of large cirques and craters). In places, these craters form rows, chains, and reefs, and at times they merge into common rings interconnected with each other. The fragments of submerged cirques and craters, which are barely noticeable because of their somewhat greater brightness and relict elevations, are called "ghost" craters.

In the extremely extensive literature on the nature of the moon, purely descriptive surveys have predominated until recently; these and limited selections of data referring to one particular category of elements of the lunar relief have been typical features of selenology. At the present state of the art, writes Khabakov, these selenotopographic descriptions have lost their significance and represent a stage which has already been attained. The main trend in the study of the lunar relief should now be a comprehensive comparative observation of the complex nature of the lunar features with the purpose of determining their inherent physical properties, such as their color, albedo, polarization, spectrophotometric characteristics, etc. The author emphasizes the great theoretical importance of morphogenetic studies aimed at determining the stages in the historical development of the moon's surface as a whole.

The launching of an artificial satellite which would revolve for a long time around the moon, as was proposed by A. A. Yakovkin, would be the most efficient method of solving the entire set of scientific problems connected with the study of the figure of the moon, Khabakov concludes.

SECTION VI. LUNAR SEISMICITY

To date, most of our knowledge regarding the moon and its structure is inferential, deduced by observations and measurements of the reflected sunlight, radio waves, and the infrared rays of the hardened moon. As a result of indirect deductions concerning numerous aspects of lunar structure, a great many points are in doubt and some are the subject of heated controversies. According to V. Zharkov and V. Berikashvili [14], these doubtful points cannot be resolved with certainty until instrumented probes actually achieve a soft landing on the surface of the moon. Plans are now afoot to land a seismograph on the moon and then create a mild shock some distance away. The resulting moonquake waves will provide information about the moon's material, just as natural shocks do on earth.

Considering that pressure levels likely to exist at the center of the moon do not exceed 50,000 atm and the compression of the lunar matter at such pressures does not exceed several percent, it can be assumed that the moon is a homogeneous body and that the velocities of the lunar seismic waves, both longitudinal and transverse, are constant. The actual thickness of the lunar crust, and whether it exists at all, is still unknown. Observation of seismic waves with a seismograph may dispel any doubt in this respect. It now appears reasonable to assume that the moon has a rather large, molten core.

The main difficulty in carrying out a lunar seismic experiment is the problem of soft-landing a capsule containing a seismograph and radio equipment. Acceleration due to gravity at the surface of the moon is 162 cm/sec^2 , about one sixth that on the earth. The wide range of lunar temperatures may make it necessary to provide thermostatic equipment. At least several tremors must be recorded in order to determine the nature of the moon's inner structure. Estimates of thermal stresses caused by the cooling and heating of the moon's interior indicate that 10 to 100 major lunar quakes might occur on the moon within one month. Considering the small size of the moon, even a minor quake would be recorded at any point of its surface.

Another source of seismic activity is provided by meteorites. According to Zharkov and Berikashvili, an average of one to six large meteorites fall on the moon every year, giving rise to appreciable tremors.

The recording of the first lunar tremors will convey an image of the seismic activity on the moon and provide information on the thermal regime of the moon's interior, volcanic activity, and the exact number of large meteorites falling on the moon.

SECTION VII. RADIO ECHO STUDIES

In addition to visual and photographic methods of studying the moon, radio emissions and radar reflections from the moon have recently been used as indicators of the nature of the lunar surface layer. The application of radar techniques also made it possible to measure the distance to the moon by evaluating the time needed for a radar signal to return after being reflected by the moon's surface. Range measurements have been made to an accuracy of 300 to 600 m. The accuracy of measurement is partially limited by the fading of the echo which makes it difficult to define the leading edge of the moon precisely. Radio-astronomical methods can be used to examine the question of the existence and density of the lunar ionosphere by measuring the refraction during occultations of sources of radio emission. The answering of these questions is acquiring an increasingly greater practical significance in view of the coming trends in the development of astronautics [15].

The first attempts to study the moon by radio methods go back to the early twenties. The Soviets announced their first successful radar contact with the moon in 1946. N. L. Kaydanovskiy [15] has stated that the interest in studying the reflection of radio waves from the surface of the moon had been lately increased due to the obvious possibility of using the moon for long-range radio communications and for radio navigation in the microwave range. Furthermore, lunar radar and radio-astronomy methods are said to have found application in the study of the propagation of radio waves through the entire terrestrial ionosphere and troposphere. Kaydanovskiy believes that "...a considerable part of the surface of the moon, which is responsible for the reflection of most of the energy in the echo, is indeed relatively smooth. Perhaps the surface of the floors of the numerous craters and valleys, filled with solidified lava and covered with a layer of dust, could be of this nature."

"It is interesting to note," the author continues, "that, under terrestrial conditions, a mirror reflection and a 'bright' spot were also observed in radar studies of dry, sand-covered deserts, conducted from the air. The effect of the lunar mountains and crater walls is manifested in the fact that they yield random scattering and produce a lengthening of the pulse, fine structure, and fluctuations caused by libration. The available experimental data are still insufficient for a full quantitative interpretation of the picture of the scattering of radio waves by the surface of the moon. Without doubt, a considerable part of the power of a reflected pulse represents coherent radiation reflected specularly from the relatively smooth section of the front edge of the moon and from certain more distant, but suitably oriented, areas. This is confirmed not only by the period of

the reflected pulse, but also by the fact that the intensity of the reflected signals (obtained by B. S. Yaplee et al.) exceeded by 5 db that computed for a rough moon with an incident-pulse period of 2 μ sec. At the same time, it appears that reflection from the moon cannot be computed in the same way as a reflection from a mirror-like sphere. The value of the dielectric permeability of the lunar crust (obtained under this assumption by T. B. A. Senior and K. M. Siegel), $\epsilon = 1.07$, is too low, while the value of the equivalent conductivity, $\sigma = 0.00048 \text{ ohm}^{-1} \cdot \text{m}^{-1}$, is too high." Kaydanovskiy concludes that further study of the reflecting properties of the lunar surface connected with its topography will be possible when antennas with a sufficiently high resolution are used.

The results of radio-astronomical studies of the moon are summarized by Kaydanovskiy in Table 1.

Table 1. Observation of the radio emission of the moon during lunation

λ , cm	T_0 , °K	T_a , °		n, %	δ	$\frac{\delta}{\lambda}$	Comment	Authors
0.8	197	32	40	16	2.2	2.75	Temperature of the central region of the moon	A. Ye. Salomonovich
0.85	150						Accuracy $\pm 40\%$	Hagen
0.86	183	40	40	22	1.5	1.75	Temperature of the central region	Gibson
1.25	292						Single measurement	Dicke and Beringer
1.25	215	36	45	17	1.65	1.31	Average temperature over the disk: work contains errors	Piddington and Minnett
1.6	219	39	34	18	2.0	1.23	Temperature of the central region	M. R. Zelinskaya, V. S. Troitskiy and L. N. Fedoseyev
3.2	130	<7	—	<8	>4	>1.25	Average over the disk; work contains an error in the absolute calibration	N. L. Kaydanovskiy and others
3.2	183	<13	—	<7	>4	>1.25	Average over the disk	V. S. Troitskiy and M. R. Zelinskaya
10	130	10	—	<8	—	—	Same	N. L. Kaydanovskiy and others
10	215	—	—	—	—	—	Single measurement	Piddington
10	315	75	—	24	—	—	Average over the disk	Akabane
21	245	0	—	0	—	—	Same	Westerhout
25	212	—	—	—	—	—	Single measurement	Piddington
33	208	0	—	0	—	—	Average over the disk	Dennis and Lerou
75	185	0	—	0	—	—	Same	Seeger and others

T_0 - Constant part of the temperature, λ - wavelength,
 $\delta = \beta/\chi$; $n\lambda = T_a/T_0 \cdot 100$, T_a - amplitude of the variable part, ζ - phase lag

The wide discrepancy between the values of the constant component of the mean temperature arrived at by the authors listed in this table is ascribed to the difficulties encountered in the absolute calibration of antennas and receivers. Kay-

danovski believes that temperatures most likely to exist on the moon are those estimated by A. Ye. Salomonovich and J. E. Gibson for the equatorial region (197 and 183° K, respectively, for $\lambda = 0.8$ cm) and V. S. Troitskiy and M. R. Zelinskaya, and C. Seeger for the lunar disk (183° K for $\lambda = 3.2$ cm and 185° K for $\lambda = 75$ cm, respectively). These data corroborate the independence of the constant temperature component of the wavelength. It is emphasized, however, that this conclusion needs further verification by more accurate measuring methods to be used over the widest possible range. A systematic increase in the constant mean-temperature component with increasing wavelength and, consequently, with the increasing depth of the layer, would indicate the presence of a heat source in the moon's interior.

The variable component of the lunar temperature also varies within a wide range. But here, in spite of the scattering due to inaccurate calibration of the instrument, a relation to the wavelength is quite obvious. Except for measurements by Akabane at the 10-cm wavelength (apparently inaccurate), the relative amplitude of the variable component, T_a/T_0 , decreased with the increasing wavelength in all measurements. With the exception of Akabane, no one has yet been able to determine temperature changes during lunation at a wavelength exceeding 3 cm. A symmetrical distribution of brightness was observed when the temperature of the central region came close to the extreme. A measurement of the relative amplitude makes it possible to estimate the value of $\delta = \beta/\chi$, which equals the ratio of the depth of penetration of an electromagnetic wave to that of a thermal wave, even in the absence of an absolute calibration of the telescope. The values of δ and δ/λ computed this way are listed in Table 1.

If, as for a number of other known solid dielectrics, the tangent of the loss angle for the material of the lunar crust

$$\operatorname{tg} \Delta = \frac{4\pi\sigma}{\epsilon\omega} = \frac{2\pi\lambda}{c\epsilon} = \text{const}$$

does not depend on the wavelength, then, for a homogeneous lunar crust,

$$\chi = \frac{4\pi\sigma}{c\sqrt{\epsilon}} = \frac{2\pi}{\lambda} \operatorname{tg} \Delta \sqrt{\epsilon}$$

and, consequently,

$$\frac{\delta}{\lambda} = \frac{\beta}{\lambda\chi} = \frac{\beta}{2\pi \operatorname{tg} \Delta \sqrt{\epsilon}}$$

should not be dependent on the wavelength λ either.

No dependence of δ/λ on the wavelength was observed within the range of wavelengths from 1.25 to 3.2 cm. However, an appreciable increase in the δ/λ value can be noticed for the

layer close to the surface, where radiation at wavelengths 0.8 to 0.86 cm originates. This, Kaydanovskiy states, may serve as an indication of the inhomogeneity of the lunar crust and the existence of a layer near the surface having smaller dielectric losses and smaller thermal conductivity than the underlying layers. In view of the limited amount of experimental data available, the author does not believe that such a statement can be made without reservation. Further study of the lunar temperature within the millimeter wave range appears therefore all the more important.

Radio echo studies of the moon are being conducted in the Soviet Union at the Radio-Physics Institute of Gorkiy University im. Lobachevskiy (NIRFI), at the Physics Institute of the Academy of Sciences, USSR, and at the Pulkovo Observatory. According to Professor V. S. Troitskiy [16], members of the Radio-Physics Institute have for the past 3—4 years studied radio waves from the moon at 20 different wavelengths, ranging from 0.1 to 70 cm, and some 30,000 measurements were carried out. Included in this vast project were studies of the thickness of the radiating layer and the dielectric constant of numerous rocks and minerals. The results of these experiments made it possible to set certain criteria regarding the nature of lunar matter. Also, measurements of the heat conductivity of similar rocks, carried out at the Leningrad Institute of Precision Mechanics and Optics, have yielded important information about the structure of the uppermost lunar layer.

It now appears that the density of the lunar matter increases slightly with depth. Electronic computers showed that density increases 1.5 to 2 times from the surface to a depth of 3—4 cm, remaining constant below that level. Knowing the reflection coefficient of radio waves, it is possible to determine the density of the silicate cover, since the degree of reflection depends on the density of the matter. The surface layer of lunite was thus found to have a density equal to one-half the density of water. Below the 3—4-cm level the density presumably comes close to 1.

Exact measurements of lunar temperature using radio waves has made the determination of lunar-matter heat conductivity possible. This heat conductivity varies with depth and is directly proportional to density. At levels below 3—4 cm heat conductivity was found to be 50 to 100 times lower than that of common terrestrial rocks. This, in Troitskiy's view, points to an extremely porous (most likely hard-porous, rather than powdery) lunar matter.

The depth of penetration of radio waves into the lunar rocks provides a source of information about the chemical and mineralogical composition of the lunar matter. Troitskiy has investigated the depth of wave penetration for various terrestrial rocks and compared it with that obtained for the moon. He concluded that the upper layer of the moon, at least 1 m

thick, contains basic and intermediate rocks, such as volcanic ash and tuffs. The topmost layer, about 1—2 cm thick, exhibits a wave-penetration depth twice as small, and it may consist mainly of stony meteorites and volcanic ashes.

Experiments have shown that the moon's temperature increases with wavelength up to 25—30 cm. The only consistent explanation for this is that the longer the wave the greater the depth of the layer about which information is provided. Consequently, an increase in temperature with wavelength indicates that lunar temperature increases with depth. It was established that temperature increases with depth almost linearly, by 2—4 degrees per meter down to a depth of 6—10 m, where the temperature is 25—30° C higher than at the surface. The increase in temperature suggests the existence of a heat flow from the moon's interior. This heat flow appears to equal one millionth of a calorie per second for each square centimeter of surface, which is the same as that of the earth. The heat flow is attributed in both cases to the radioactive decay of uranium, thorium, and potassium isotopes. Assuming that the earth and the moon have both already reached a state of balance between heat generation and heat flow, the number of calories generated for 1 gram of matter per unit time is 4—5 times greater for the moon than it is for the earth. It can be inferred that the content of radioactive elements per gram of matter is by as many times greater for the moon as it is for the earth.

Early considerations regarding interior temperatures started from the premises that the moon was formed cold and has stayed rigid throughout its existence, in apparent agreement with its frozen-exterior appearance and with the dormant aspect of this body as a whole. Subsequently, when the first hypotheses arose concerning the plutonic origin of the maria, it became reasonable to assume that the moon was formed hot and has been cooling off gradually ever since. Since the discovery of radioactivity, such assumptions have no longer been necessary, since this source alone can account for a very large amount of heating of native lunar materials. Troitskiy [16] derived estimates of the interior temperature distribution of the moon on the basis of fissionable heating processes. He postulated that the moon has a hard core, that the temperature in its interior does not exceed the melting point of the silicates, which is 1500° C, and that radioactive elements are concentrated (just as they are in the earth) in the upper mantle. The radioactive layer is said to be 15—20 km thick at the maximum, and 1000°-C temperatures are believed to prevail starting at depths of 50 km. Temperature estimates made by non-Soviet selenologists have indicated that such a temperature exists at a depth of 400—500 km. These estimates were based on the assumption of a low concentration of the radioactive elements. The proximity of a hot interior was evidently corroborated by observations carried out at the Pulkovo Observatory, which brought to light the emission of hot gases from the central peak of Alphonsus.

Almost all of the data given above were derived from the observation of radiation coming from the entire lunar disk and thus are average values for the entire surface of the moon. Infrared measurements of various individual areas revealed, however, that thermal and electrical properties, as well as the chemical composition, of lunar matter are all alike. It is safe to say, Troitskiy concludes, that the seas do not differ appreciably from the continents in their composition. The earlier belief that the darker seas consist primarily of basalt while the lighter continents consisted of granite is said to be no longer true. Up to the present time there have been no reports of the association of particular radio echos with prominent features of the lunar surface.

SECTION VIII. LUNAR ATMOSPHERE

The existence of a possible lunar atmosphere has been explored in the Soviet Union chiefly by Yu. N. Lipskiy, V. G. Fesentkov, N. A. Kozyrev, I. S. Shklovskiy, and N. N. Sytinskaya. Two approaches were used: the interpretation of experimental measurements of the lunar disk, and theoretical calculations concerning the moon's ability to retain gaseous molecular matter. A detailed presentation of the present state of the art was given by N. N. Sytinskaya [17]. Following are excerpts from Sytinskaya's paper titled "The problem of the lunar atmosphere."

In recent years, the problem of the lunar atmosphere has again become the subject of lively discussion. Some authors have come out in favor of the existence of an atmosphere on the moon, which, although highly rarefied, is still optically and physically perceptible. However, a detailed study of the question involving, among others, entirely new radio-astronomy methods, makes it necessary to recognize that the medium adjacent to the lunar surface is not physically distinguishable from the vacuum of interplanetary space. Apparently, one can speak only of a temporary appearance of gases in one region or another of the lunar surface, these gases being given off in meteorite explosions or in possible manifestations of lunar volcanism.

If the moon had a gaseous envelope, this would have to be revealed during the occultation of other celestial bodies by the moon. The search for the resulting phenomena, which has been going on for almost three centuries, is complicated by the fact that we are dealing here with three different events occurring simultaneously: a shifting of the image of the star due to refraction; a decrease in brilliancy of the image resulting from the refraction deviation of the rays; and a diffraction at the moon's edge. In the occultation of stars by the moon, an atmosphere will manifest itself only in a shift of the star and in a corresponding reduction in the visible radius of the lunar disk. If the accuracy of observation is limited to $0''.1$, the refraction method would permit the detection of a lunar atmosphere with a density $1/300$ the density of the terrestrial atmosphere. Since the moon cannot possibly have such a gaseous envelope, it is understandable that persistent attempts to uncover this envelope by studying stellar occultations have led nowhere.

The first to use a polarimetric technique for examining the possibility of the moon having an atmosphere was V. G. Fesentkov, who examined the central region of the moon's disk with a polaroid filter at times of quadrature, examining the darker side of the terminator. If the moon possessed an atmos-

phere, the light diffused in it at this place would be polarized; however, Fesenkov detected no change in the brightness of the observed areas when the polarizing filter was rotated. Assuming that the coefficients of scattering in the moon's and in the earth's atmosphere were the same, he said that an atmosphere of vertical mass 10^{-6} of that of the earth's atmosphere would have been detectable. Subsequently, it was found that the ashen light was itself strongly polarized and was some 100 times brighter than such an atmosphere.

Following Fesenkov's idea, Yu. N. Lipskiy again observed the center of the moon's disk at first and last quarters, but this time with a photopolarimeter utilizing green light centering on 5300 Å. He deduced that the density of the moon's atmosphere at the lunar surface was probably not more than 10^{-4} times that of the earth's at sea level.

In the final analysis, all observations designed to detect a lunar atmosphere have so far failed to do so. More definite results are expected from radio-astronomical observations. This technique is based on the assumption that if the moon has a layer of extremely rarefied gas, the molecules of such a gas would be ionized by solar radiation on the daylight side of the moon. Upon the passage of radio waves coming to us from cosmic radiation sources, the beam would bend due to refraction; the magnitude of the deviation would depend on the density of the ionized particles in space. When the moon eclipses a source of radio emission, this refraction, theoretically, will manifest itself in a certain increase in the radius of the lunar disk as compared with its value determined from optical observations. The effect can be detected by an accurate determination of the duration of the eclipse, which will be somewhat increased if there is an ionized atmosphere.

The moon's atmosphere is so tenuous that it can have no appreciable effect on the motion of even small fractions of micrometeors and provides no protection against ultraviolet radiation, x-rays, gamma-rays, and cosmic radiation. Radio-astronomical observations have thus confirmed the widespread opinion that a lunar atmosphere is practically nonexistent.

CONCLUSION

The papers presented in this report are representative of the state of knowledge on lunar surface materials and their characteristics as reflected in the latest Soviet open-literature publications. Much Soviet effort in lunar studies has been directed toward the problems which will have to be solved in order to ensure a tolerable margin of safety for the astronauts who will be going there. Soviet views on the lunar surface layer, often contradictory and sometimes hardly acceptable, are summarized in the following paragraphs.

Russian astronomer N. Barabashev believes the lunar surface layer to consist of disintegrated tufa-like rock, with grains ranging in size from 3 to 10 mm in diameter, while the layer itself is no more than 3 cm deep. V. V. Sharonov and N. N. Sytinskaya, of Leningrad, have developed a theory that the surface is made up of slag-like material, since a meteorite hitting the crust would cause a temporary "hot spot" where the surface would be vaporized, with the vapor condensing and falling back to the ground, producing a slag coating. The existence of soil-forming agents that would favor granular over cohesive surface materials has been argued by Soviet writers, but general agreement prevails regarding the presence of some dust on the moon.

Results from photometric and polarimetric studies of the moon and terrestrial materials have been discussed by V. G. Fesenkov, N. S. Orlova, N. P. Barabashev, A. Markov, V. V. Sharonov, and others. Some general conclusions reached on the basis of these studies are: the photometric function is nearly the same for all regions of the lunar surface; color differences on the moon are small; the polarization is nearly constant in magnitude and direction for the highlands, but varies irregularly over the maria; the photometric properties suggest a porous surface layer, existing even in the steepest slopes; and the polarimetric results are interpreted by Fesenkov and Orlova to imply that the surface layer consists of agglomerations of grains considerably greater than the wavelength of the visible light. Attempts to find ordinary terrestrial materials having photometric and polarimetric properties similar to those of the moon have met with little or no success.

Having reviewed the results of infrared measurements of the lunar surface temperature, M. S. Zel'tser concluded that most of the surface is covered with a dust layer with a thickness of at least 5 cm. Coefficients of radiation in the infrared region and the difference in the thermal inertia ($k\rho c$)^{-1/2} between sea and continental regions of the lunar surface were determined by M. N. Markov and V. L. Khokhlova. The near agreement of temperatures obtained at wavelengths of 3.6 and 8-13 μ suggests that the moon is a gray or nearly gray emitter.

The detection of thermal radiation from the moon in the microwave range was accomplished at 0.4, 3.2, 9.6, and 35 cm by V. S. Troitskiy. The relatively small amplitude of the variation of microwave temperature with time, and the lag in phase, implies clearly that emission at these wavelengths arises from below the lunar surface. Troitskiy found indications that temperature increases with depth within the surface layer that is about 20 m thick. Observations of emission at these longer wavelengths are usually taken as averages over the whole disk of the moon. It appears to be premature to make conclusive statements about the subsurface physical properties implied by microwave results, since a substantial variation in these properties must exist over the lunar disk.

The question of whether the moon possesses a magnetic field is still unsettled. In September 1959, a Soviet rocket containing a magnetometer crashed on the moon; no evidence of a lunar magnetic field down to the instrument threshold of 6×10^{-4} gauss was indicated.

The mechanism of lunar seismic energy release may be entirely different from that on earth. Preparations are now under way to soft-land a seismograph on the moon. A knowledge of whether moonquakes are localized in belts or are random in location, their correlation with any lunar topographic features, and their depth of focus is essential for understanding the thermal and tectonic history of the moon. Finally, a great deal of new information about the moon can be expected from the rapidly developing field of lunar radar astronomy. Soviet scientists actively engaged in lunar radar research include V. A. Kotel'nikov, N. L. Kaydanovskiy, V. S. Troitskiy, and M. R. Zelinskaya.

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